TRIGGERING OF SURFACE DISCHARGE SWITCHES*

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Abstract

The performance of a triggered 45 kV surface discharge switch operated in air, was investigated. Trigger performance evaluations include jitter measurements, channels per meter and the effects of charging voltage and trigger electrode polarity. Trigger electrode constraints, including positioning of the electrode and trigger pulse risetimes, are discussed. Multichannel performance of various dielectrics including G-10, Delrin, and Lucite are compared. Voltage and current measurements were the principle diagnostics used in the evaluation of the switch performance. The addition of an auxiliary electrode (which provides UV preillumination and added field distortion) is discussed.

Introduction

The multichannel characteristics of a surface discharge switch (SDS) makes it attractive to fast switching applications [1,2] which require low inductance switches. Commonly used surface discharge switches are over-voltaged by several hundred percent and allowed to self-break [3,4]. Overvoltaging the switch usually creates dense multichanneling when the switch closes. Likewise, triggered SDS's are usually pulse charged and triggered before self-break occurs. The pulse charging allows overvoltaging of the switch, thus causing dense-multichanneling and low jitter.

Little information is available about DC charged surface discharge switches, therefore they are generally not employed. Difficulties arise when the SDS is DC charged. Triggering of the switch is generally difficult if multichanneling and low jitter are required. A comparative study of the effects of different parameters on the characteristics of DC charged SDS's is underway and the preliminary results are reported here. The parameter studies include different dielectric substrates, charging voltage polarity, and trigger pulse polarity effects. The characteristics of the switch under these various conditions are discussed in the rest of this paper.

Circuit Operation and Design

The surface discharge switch was constructed as part of a 1 m long, 6 Ω strip line. The electrodes are easily adjustable to various spacings and are presently constructed of brass. The electrodes shown in Fig. 1 are 20.3 cm long and 1.27 cm thick. A Blue Nylon dielectric, .63 cm thick and 30.5 cm wide, provides the insulation between the charged side of the transmission line and the ground return side. A slot, 33 cm long and .16 cm deep, was milled into the Blue Nylon line in which a G-10 insert is placed. The main trigger electrode which consists of a 2.54 cm wide strip of 2 mil thick copper tape is placed

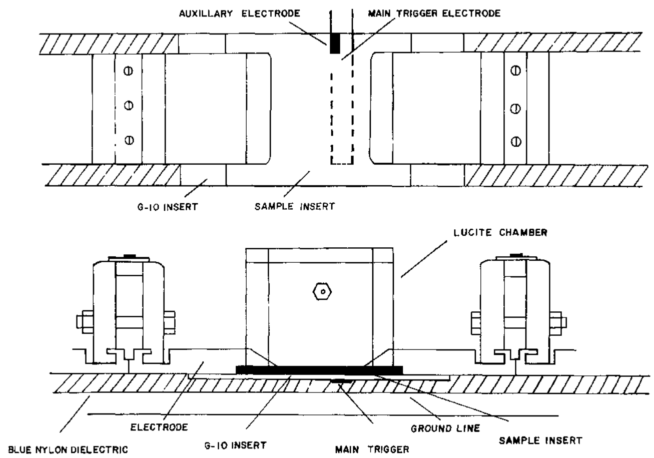

Fig. 1. Surface Discharge Switch

between the G-10 insert and the Blue Nylon,with the main trigger located 3 cm from the charged electrode. The G-10 insert isolates the trigger from the two main electrodes when the trigger pulse is applied. The electrode spacing is set at 6.2 cm to give self-break voltages between 45 and 55 kilovolts. For the 6.2 cm separation a surface discharge insulator sample with dimensions .16 cm x 30.5 cm x 12 cm is held in place by the electrodes. In addition to the main trigger, an auxiliary electrode is placed on the surface of the sample, at its edge. The auxiliary electrode provides additional field distortion and UV preillumination. The auxiliary electrode was a .63 cm wide 2.5 cm long strip of 2 mil copper tape. The auxiliary electrode is placed 5.2 cm from the edge of the sample and 2.54 cm from the grounded electrode so that an arc occurs between this electrode and the grounded electrode when the trigger pulse arrives. A Lucite chamber is placed over the electrodes and filled with dry air at atmospheric pressure.

The energy is stored in four parallel, 25 Ω cables which are attached to the 6 Ω transmission line (Figure 2). The four cables are DC charged through a 2 MΩ resistor. The 20 m long lines provide a 200 ns wide pulse into the 6 Ω load. The distributed capacitance of the four cables is .0174 μf, giving a 13.9 joule discharge when charged to 40 kilovolts. When a trigger pulse is applied to the trigger electrodes the switch breaks down, discharging into the 6 Ω load. The load consists of 6 ea, 1 Ω ceramic disk resistors. The inductance of the load was measured and found to be about 220 nH. A 50 kV pulse with a risetime on the the order of 5 ns (10%-90%) is applied to initate breakdown (Figure 3). The voltage on the trigger strip and on the load were monitored with capacitive probes built into the transmission line, while the current was monitored with a Pearson coil.

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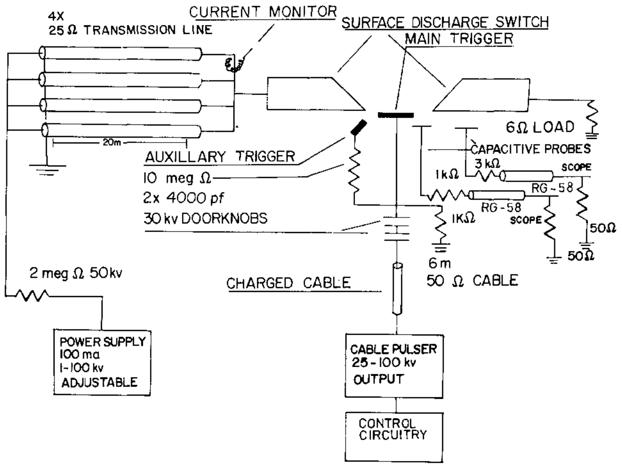


Fig. 2. Experimental Setup

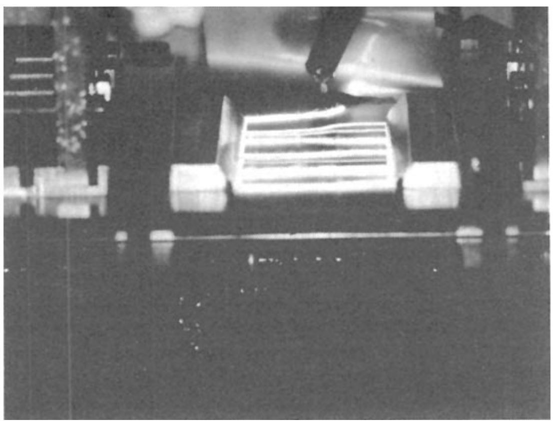
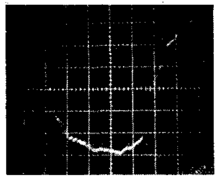


Fig. 3. Multichanneling of Surface Discharge Switch

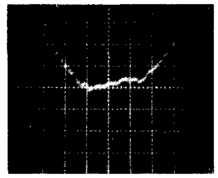
Results

Three dielectrics (G-10, Delrin, Lucite) were tested in dry air under all possible charging and trigger polarities. Results are given in terms of the multichanneling characteristics, load voltage, current and jitter measurements. Throughout the tests a 50 kV trigger voltage was used , while the charging voltage was kept constant at 40 kilovolts. The repetition rate was 1.3 pulses per second.

G-10 had the best characteristics of the three materials tested (Table 1). The first case tested was with negative charging voltage and positive trigger. The voltage fall time was 70 ns and the current fall time 70 ns (Figure 4). The jitter of five shots was 16 nanoseconds initially; however, after 500 shots it decreased to 5 nanoseconds (Figure 5). Multichanneling characteristics also changed as the material eroded away. Initially about 15 channels per meter were visible, however after 500 shots about 40 channels per meter were typical (Figure 6). All other electrode polarity combinations gave considerably worse performance. For the case of positive charging and trigger voltages the voltage risetime was 120 ns and the current risetime approximately 70 ns. Multichanneling was poor, resulting in only two channels per meter. The jitter dropped from 140 ns to approximately 30 ns, during the first 500 shots. Likewise for the negative charging, negative trigger voltage, the voltage fall time remained about 120 ns and the current fall time 70 ns. The jitter, however, was too great to measure. Characteristics of this case included a large number of prefires and lower self-break voltages. The self-break voltage decreased from 45 to 36 kV after 500 shots. In the last case, of positive charging and negative trigger voltage, the voltage and current wave shapes varied from shot-to-shot. The voltage risetime on the average was about 100 ns and the current risetime was up to 100 ns. The jitter was approximately 100 ns. Multichanneling decreased from 25 channels per meter to 15 channels per meter during the first 500 hundred shots. Prefires and misfires were common in this case.

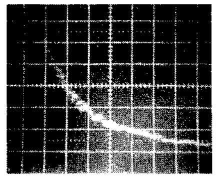


A. Voltage Measurement across a 6 Ω load, 3340 V/div; 50 ns/div.

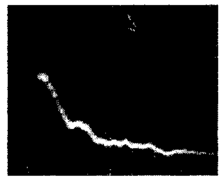


B. Current Measurement through a 6 Ω load, 1000 A/div; 50 ns/div.

Fig. 4. Voltage and Current Measurements on G-10 for a Negative, 40 kV, Charge Voltage and Positive, 50 kV, Trigger.

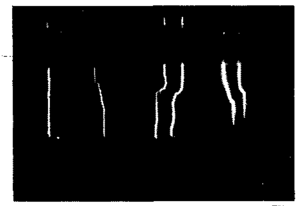


A. Jitter of first 5 shots. 3340 V/div; 20 ns/div.

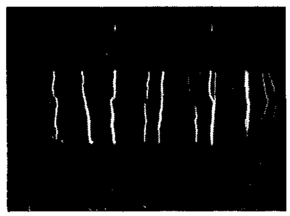


B. Jitter of 5 shots, after first 500 shots. 3340 V/div; 20 ns/div.

Fig. 5. Jitter of 5 Shots on G-10.



A. Multichannel Characteristics of First Shot



B. Multichannel Characteristics after 500 shots

Fig. 6. Multichannel Characteristics of G-10 over a 20.3 cm Length and 6.2 cm Electrode Separation.

The performance of Delrin was similar to that of G-10 (Table 2). For the case of negative charging and positive trigger voltages, the voltage fall time was 80 ns and the current risetime 70 ns (Figure 7) with a jitter of approximately 15 ns. Multichanneling

A. Voltage Measurement across a 6 Ω load, 3340 V/div; 50 ns/div.

B. Current Measurement through a 6 Ω load, 1000 A/div; 50 ns/div.

Fig. 7. Voltage and Current Characteristics of Delrin for a Negative, 40 kV, Charge Voltage and a Positive, 50 kV, Trigger Pulse.

remained stable at 25 channels per meter for the entire run (Fig. 8). When the voltage and current waveforms using Delrin are compared to the voltage and current characteristics using G-10 (Fig. 4), under the same conditions, a dramatic difference is seen in the voltage wave shapes and risetimes. Delrin gave significantly greater jitter and slower risetimes. The effect of different trigger and charging polarity combinations is also apparent when the two cases of positive trigger and positive charging voltage (Fig. 9) are compared with the most successful case of negative charging voltage and positive trigger (Fig. 7). The most significant change is in the risetime of the voltage across the load.

Multichanneling for a 6.2 cm Electrode Separation and 20.3 cm Electrode Length.

Fig. 8. Multichanneling Characteristics of Delrin For A Negative Charge Voltage of 40 kV and a Positive 50 kV Trigger Pulse.

A. Voltage Measurement Across a 6 Ω load, 3340 V/div; 50 ns/div.

B. Current through a 6 Ω load, 1000 A/Div; 50 ns/div.

Fig. 9. Voltage and Current Measurements on Delrin for a Positive, 40 kV, Charge Voltage and a Positive, 50 kV, Trigger Pulse.

Results using lucite differed considerably from those using G-10 or Delrin (Table 3). Once again a negative charging voltage and a positive trigger pulse gave the best overall results. The 80 ns fall time of the voltalge acorss the load and the 70 ns current risetime (Fig. 10) compared favorably with the similar cases for G-10 and Delrin. However, multichanneling decreased to only 2 channels when the switch was triggered. Unlike the G-10 results, the jitter was too great to measure for three of the charging-trigger voltage combinations, but no prefires or misfires were observed.

A. Voltage Measurement Across a 6 Ω load, 3340 V/div; 50 ns/div.

B. Current through a 6 Ω load, 3340 V/Div; 50 ns/div.

Fig. 10. Voltage and Current Measurements on Lucite for a Negative, 40 kV, Charge Voltage and a Positive, 50 kV, Trigger.

In addition to voltage and current measurements static field measurements were made to check for residual charge. In the case of negative charging voltage and a postive trigger pulse, positive charging of the insulator was measured over the main trigger electrode. Near the cathode the insulator was charged negative. The charge decay directly above the trigger was checked and charges were found to decay only 10 percent in one hour. Charges on the insulator for the case of negative charge voltage and negative trigger polarity were also checked. Negative charging on the insulator, above the trigger and near the cathode, was measured. The last case of positive charge voltage and negative trigger polarity was also checked and the insulator charge found to be positive.

Conclusion

The auxiliary electrode was found to provide denser multichanneling, in the case of the negative charging and positive trigger voltages, on G-10 and Delrin. The reason for the increased multichanneling due to the auxiliary electrode in this one case is not clear. This increase may be due to UV preillumination or to added field distortion. However, in the remaining cases the auxiliary electrode did not play a significant role in the multichanneling characteristics.

The data presented indicate that only certain dielectrics and a specific combination of charging voltage and trigger pulse polarities work well for the DC charged, triggered surface discharge switches. The voltage waveforms of G-10 (Figure 4) and Delrin (Figure 7) indicate that the dielectric plays a significant role in the discharge process. The multichanneling characteristics of G-10 (Figure 6) and Delrin (Figure 8) also show the dependence of the discharge process on the dielectric used. The basic physics of the trigger process and the dependence of the multichanneling process on the dielectric are not fully understood at this time. However, preliminary static charge measurements indicate that residual charges and surface resistivity influence the triggering. The charge measurements indicate significant charging of the insulators and a slow decay time of these charges. Future studies will concentrate on isolating the basic trigger processes and understanding them.

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	CHARGE VOLTAGE POLARITY	TRIGGER PULSE POLARITY	VOLTAGE RISETIME (or Fall Time)	CURRENT RISETIME (or Fall Time)	JITTER TIMES (5 Shots)	CHANNELS PER METER	COMMENTS
1	—	+	70 NS	70 NS	5 NS	39	-
2	+	+	120 NS	70 NS	30 NS	2	-
3	—	—	120 NS	70 NS	-	2	PREFIRES
4	+	—	100 NS	100 NS	100 NS	15	PREFIRES AND MISFIRES

Table 1. Characteristics of G-10

	CHARGE VOLTAGE POLARITY	TRIGGER PULSE POLARITY	VOLTAGE RISETIME (or Fall Time)	CURRENT RISETIME (or Fall Time)	JITTER TIMES (5 Shots)	CHANNELS PER METER	COMMENTS
1	—	+	80 NS	70 NS	15 NS	25	-
2	+	+	120 NS	70 NS	-	1	-
3	—	—	120 NS	70ns	-	1	PREFIRES
4	+	—	120 NS	70ns	-	1	SOME PREFIRES

Table 2. Characteristics of Delrin.

	CHARGE VOLTAGE POLARITY	TRIGGER PULSE POLARITY	VOLTAGE RISETIME (or Fall Time)	CURRENT RISETIME (or Fall Time)	JITTER TIMES (5 Shots)	CHANNELS PER METER	COMMENTS
1	—	+	80 NS	70 NS	40 NS	2	-
2	+	+	120 NS	70 NS	-	1	-
3	—	+	120 NS	70 NS	-	1	NO PREFIRES
4	+	—	120 NS	70 NS	-	1	NO PREFIRES

Table 3. Characteristics of Lucite.